Metamorphic Rocks of the Albion Basin of Cottonwood District, Utah

A Thesis
Presented in Partial Fulfillment
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Degree Bachelor of Science

by

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Abstract

The metamorphic rocks of the Albion Basin in the Cottonwood district of central Utah represent sediments of 700 to 800 feet thick where locally exposed and are of Cambrian age. The study emphasizes the affects of metamorphism, both mineralogical and physical, and the results of metasomatism by the introduction of boron and sulfur volatiles. Also included is a description of the regional geology and a description of the unmetamorphosed sediments.

Introduction

The earliest study of Little Cottonwood Canyon and surrounding areas was conducted by the Fortieth Parallel Survey[1] in the eighteen seventies. Subsequently J.M. Bontwell[2], B.S. Butler, G.F. Loughlin[3], and several others have investigated this area. However, it was F.F. Hintze[4], who upon recognizing the thrust faulting in the area, laid the groundwork for subsequent investigations, much of which has been published in mining journals.

Outcrops in the area are primarily sedimentary, ranging from pre-Cambrian to Jurassic in age. However, there are intrusive dikes and stocks of late Cretacious to Tertiary in age, which cut all earlier sedimentary rocks. Quarternary deposits are in the form of glacial and valley alluvium deposits. These appear as clay to fine sand with some large cobbles and boulders occasionally interspersed in the deposits.

The total thickness of the sedimentary rocks of this area is approximately 12,000 feet, of which 1500 feet of pre-Cambrian are exposed, but the total thickness is much greater. The pre-Cambrian consists mainly of quartzites and shales. The overlying Cambrian is 1800 feet to 2800 feet thick. The variable thickness has been attributed to the Cambrian(?) tillite which is locally thick, but not present in many sections. The remainder of the Cambrian section consists of three formations. The lowest is the Tintic Quartzite, which is an 800 to 1000 foot thick formation of very homogeneous quartzite. Next is the Ophir Shale which is a 400 foot thick section of shale with some prominant beds of limestone. The youngest Cambrian formation is the Maxfield Limestone. This formation has a maximum thickness of 500 to 600 feet, but is thinner in some localities due to an overlying inconformity.

Ordovician and Silurian rocks are absent, and only a small part of the Devonian is present, as a 150 foot thick section of dolomitic limestone.

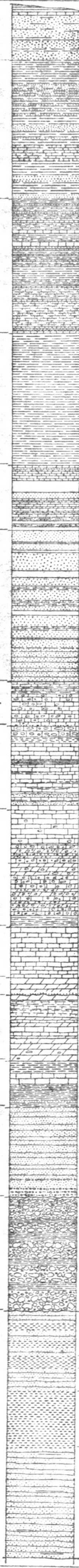
The Mississippean and Pennsylvanian section is over 4500 feet thick. Dolomitic limestone is the principal rock type, but there is also an appreciable amount of quartzite. Approximately 200 feet of Permian caps the Pennsylvanian rocks. This is also a limestone, but contains interbedded sandstone and shale.

Triassic and Jurassic formations are also present with the Triassic 3500 feet thick, and composed of shales, sandstones, and argillaceous limestone. Only 500 feet of Jurassic sandstones and shales are present. (Figure I)

The intrusive igneous rocks are large plutonic bodies and numerous dikes. The plutons form three major bodies. They are alined in an east-west direction through the Cottonwood and American Fork areas. The intrusive bodies decrease in size, coarseness of grain, and proportion of silica from west to east, grading from granodiorite and quartz monzonite, to granodiorite, to a diorite in the farthest east stock. They are progressively younger from east to west, and were probably intruded over a short time span. The dikes, which intrude the area, and are contemporanious with the stocks, strike for the most part, northeasterly. These are off shoots from the stocks and mostly consist of alaskite porphories or lamprophyres.

The pre-Cambrian, Paleozoic, and Mesozoic sedimentary rocks were subjected to thrust faulting, folding, and complex faulting, followed by the intrusion of the late Cretacious and Tertiary igneous rocks. There was

Figure I



System	Series		Formation	Section	Thickness (feet)	Kind of rock
Jurassic.		Jn	Nugget sandstone.			Light-colored sandstone with interbedded red shale.
Triassic(?)		Ŧa	Ankareh shale.		1,225	Red shale, locally sandy, with interbedded coarse gray sandstones. Prominent bed of light-colored hard sandstone near the middle.
Triassic.		Ŧt	Thaynes formation.		1,180	Limestone with sandstone and shale, the calcareous rocks weathering brown in part. A stratum of red shale separates a more calcareous upper portion from a more sandy lower portion.
Triassic.		Ŧw	Woodside shale.		1,175	Shale, mainly red, partly altered to green; fine-grained, thin-bedded. Ripple marks, mud cracks, and rain-drop imprints.
Carboniferous.	Permian.	Cpc	Park City formation.		575	Limestone with interbedded quartzite, sandstone, and shale and a little phosphate rock.
Carboniferous.	Pennsylvanian.	Cw	Weber quartzite.		1,350+	Fine-grained, homogeneous quartzite, white to pale gray, weathering pale buff, interbedded with calcareous sandstone and with gray limestone which is cherty in part.
Carboniferous.	Pennsylvanian.	Cmo	Morgan(?) formation.		350±	Limestone, gray, cherty. Green nodular shale and red limestone near top. Conglomerate at base, pebbles of chert and limestone.
						— Unconformity —
Carboniferous.	Mississippian.	Ch	Humbug formation.		750±	Limestone, black, cherty; large corals and other fossils near top. Limestone, black, weathering to buff, more or less argillaceous. Black shale, apparently absent in southern part of area. Limestone, gray to buff, interbedded with calcareous shale and sandstone.
Carboniferous.	Mississippian.	Cdm	Deseret limestone.		900	Limestone, dark blue to white, not much chert (300 ft.). Limestone and dolomite, dark, very cherty (250 ft.). Dolomite, whitish, crinoidal, large lumps of pale chert (100 ft.). Dolomite and magnesian limestone, very cherty; black shaly beds at base (300 ft.).
Carboniferous.	Mississippian.	Cdm	Madison limestone.		450	Limestone, partly magnesian, free from chert; blue, altering to blue and white; highly fossiliferous, especially near base.
Devonian (?)		Dj	Jefferson(?) dolomite.		150	Dolomite, mostly thick-bedded; bluish-white bed at top; flaggy and vuggy layers; sandstone at base.
						— Unconformity —
Cambrian.	Upper Cambrian.	Ꞓm	Maxfield limestone.		570	Dolomite, gray, mottled, oolitic (70 ft.). Limestone, gray to buff-mottled, interbedded with shale (150 ft.). Dolomite and limestone, mottled with buff and gray (150 ft.). White dolomite, sandy in upper part (20 ft.). Dolomite, mostly gray, lower part largely oolitic (180 ft.).
Cambrian.	Middle Cambrian.	Ꞓo	Ophir shale.		420	Shale, partly calcareous, greenish gray, yellowish brown on weathered surface. Limestone, nodular and mottled. Dark micaceous shale.
Cambrian.	Lower Cambrian.	Ꞓtq	Tintic quartzite.		800±	Quartzite, light-colored, conglomeratic layers near base.
						— Unconformity —
Cambrian(?)		Ꞓt	Tillite.		0 to 1,000	Tillite interbedded with varved shale; dark-colored, weathering rusty.
						— Unconformity(?) —
Pre-Cambrian.		pre-Ꞓ			400	White quartzite. Light-colored quartzite interbedded with purple shale.
Pre-Cambrian.		pre-Ꞓ			100	Argillite, dark purple with green areas.
Pre-Cambrian.		pre-Ꞓ			200	Rusty purple quartzite.
Pre-Cambrian.		pre-Ꞓ			500	Argillite with slaty cleavage; dark gray, stained with ocher on weathered surface.
Pre-Cambrian.		pre-Ꞓ			1,000+	Mainly quartzite, whitish to red or dull purple; upper beds fine-grained and white.

also some major normal faulting after the intrusions were implaced.

The thrust faults are mainly parallel to the bedding planes and dip essentially easterly. The sedimentary rocks were arched into a easterly dipping anticline along which the intrusive bodies are alined. The implacement of these intrusive bodies has been related to the formation of the anticline. The faults, other than the thrust faults, are steeply dipping normal faults together with some reverse faults also with steep dips.

Purpose and Location

The purpose of this study is to record the effects of contact metamorphis of sedimentary strata by a pluton. The area studied is in the Albion Basin at the head of Little Cottonwood Canyon. Only the Cambrian Tintic Quartzite, Ophir Shale, and Maxfield Limestone were sampled and examined. These formations have a general northerly strike with a dip ranging from 25 to 30 degrees easterly. These are most easily accessible on the northeastern wall of the Albion Basin, in an area approximately one mile long by a half mile wide. It also is located approximately 2.1 miles east-southeast from the town of Alta, Utah. Here the contact zone of the formations and the granodiorite Alta Stock is exposed. (Figure II)

Topography

The area under study in the Albion Basin of Little Cottonwood Canyon is an amphitheater-like extension of the main canyon. The south wall has a series of glaciated hollows. The north wall is scarred by series of gullies. These gullies are caused by water flowing from springs, which are mostly associated with faults in the area.

Albion Basin Area

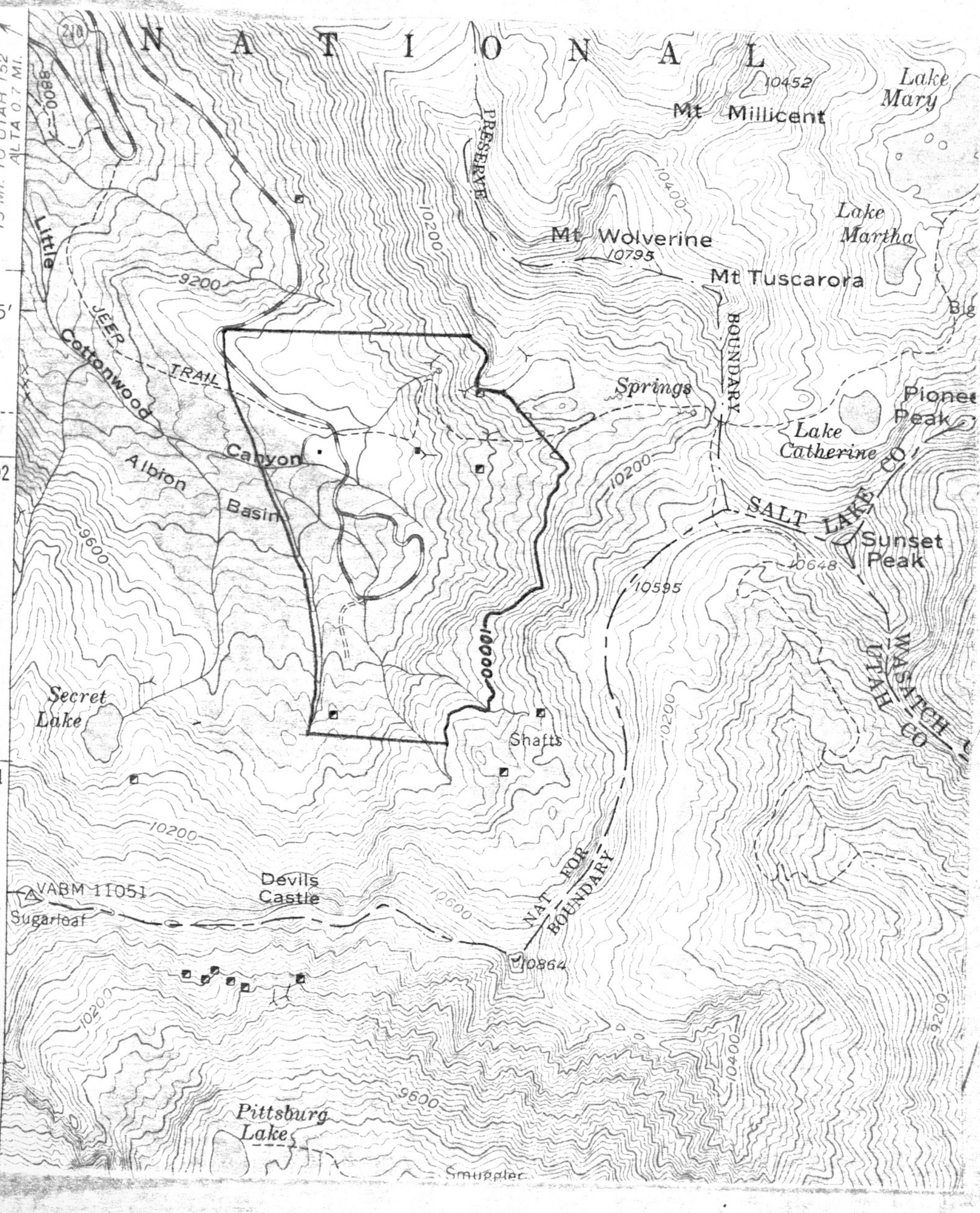


Figure II

Stratigraphy of the Cambrian Rocks

Tintic Quartzite

The Tintic Quartzite in this area of study is lower Cambrian in age. It is equivalant to the Tintic Formation of the Tintic District and the lower part of the Brigham Formation. The visible section of the Tintic Quartzite is a fairly homogeneous formation, whose primary constituent is quartzite. However, near the upper most part of the formation there are small beds of shale present. The quartzite is white to a light reddish-brown in color, and has a medium to coarse grain size. Iron oxide coats the bedding planes and joints of the formation, and is responsible for some of the rock color.

Ophir Shale

The Ophir Shale overlies the Tintic Quartzite, and due to its stratagraphic position, is considered to be equivalent to the Ophir Formation of the Ophir District. The thickness in the area of study is 350 to 400 feet. The formation is primarily shale, but the upper and lower parts are separated by an argillaceous limestone.

The lower part of the Ophir is a dark green to bluish-green color. At its base, where it contacts the Tintic Quartzite, there is interbedded quartzite. Higher in this section, bedding becomes very prominant, and ranges from thin to fissile. Finally at the top, the bedding becomes very irregular, and there is a noticeable increase in the calcium carbonate content of the rocks. This lower section of the Ophir is the thickest of the three subdivisions of the formation. The upper member is the thicker of the remaining upper and middle subdivisions.

The middle part of the Ophir Shale is a noticeably shaly siliceous limestone. This section is well defined with wavy bedding planes due to siliceous laminations, which decrease in prominance up the section.

The upper part of the Ophir Shale is yellowish-brown to red in weathered outcrops, but greenish-grey when unaltered. It is also thinly bedded, but not to the extent of the lower member. This upper section is more effected by contact metamorphism than the lower shale member due to a higher concentration of calcium carbonate. This section also exhibits a blocky fracture pattern.

Maxfield Limestone

Overlying the Ophir Shale is the Maxfield Limestone, which is a thinner formation locally than both the Tintic and Ophir formations. This formation locally is 150 to 200 feet thick.

The Maxfield passes up from a white to grey limestone with interbedded dolomite, to a buff colored argillaceous limestone. Many of the lower dolomite and limestone beds contain oolites, which impart a pisolitic texture to these rocks. Some of the limestone beds of the Maxfield were possibly organicly derived, because of the persistance of twig and worm-like structures in them. (Figure III)

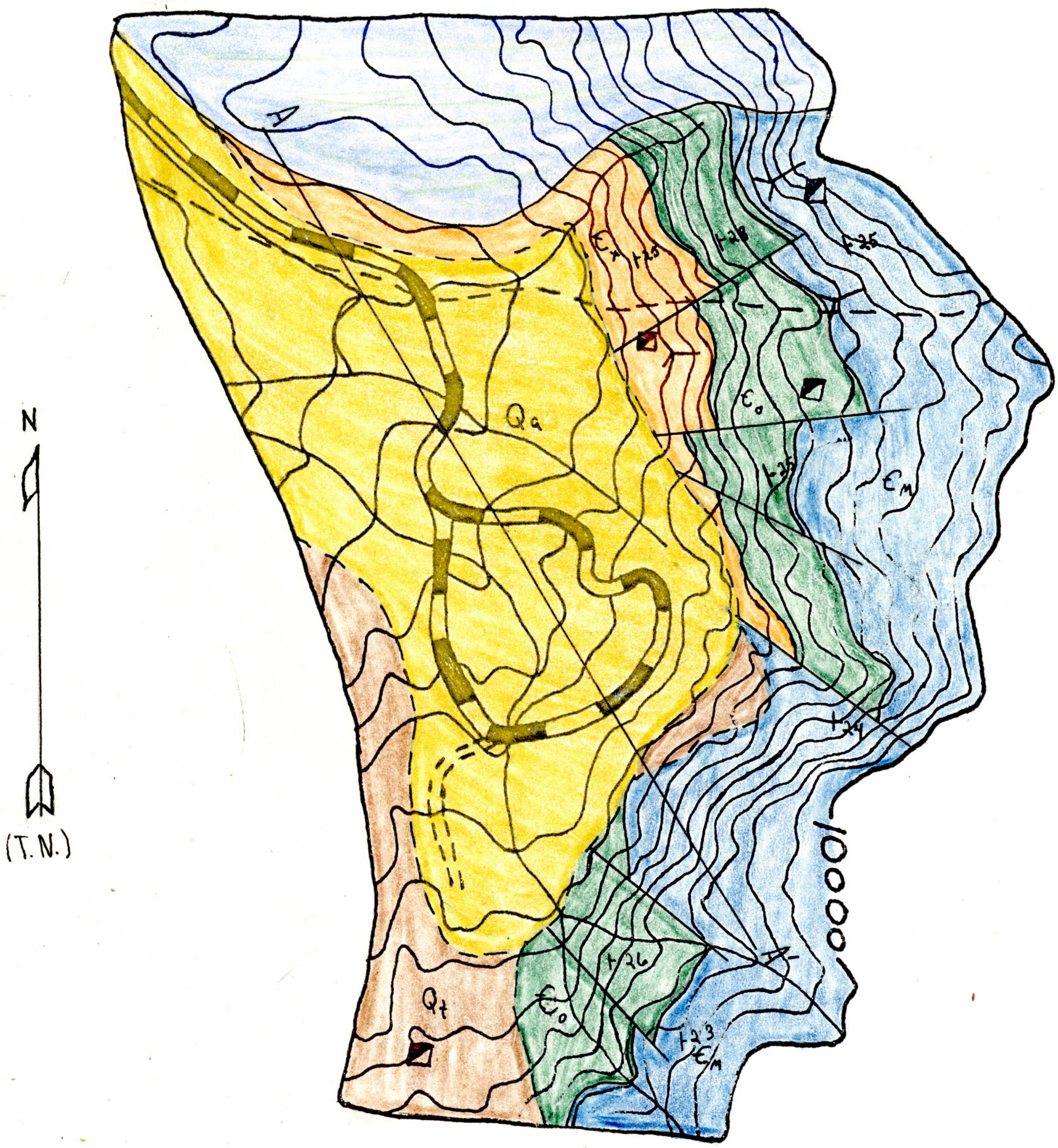
Stratigraphy of the Intrusion

Alta Stock

The igneous intrustion known as the Alta Stock is of a granodiorite composition, and is late Cretaceous to Tertiary in age. This intrusion cuts across all the rocks of the area except the most recent, namely the Quarternary deposits.

The primary constituent is plagioclase, which is often extensively zoned. There are lesser amounts of orthoclase, quartz, biotite, and hornblende. There are no pyroxenes observed in samples. Accessories

Map of the Albion Basin



Scale 1:12,000

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Figure III a

Explanation

Qt

Quaternary Talus

Qa

Quaternary Alluvium
stream gravel and
valley fill

ag

Alta Stock

light-grey nonporphyritic
biotite hornblende granodiorite

Figure III b

Explanation (cont.)

Єm

Maxfield Limestone

Dark-grey oolitic dolomite and limestone

Єo

Ophir Formation

Upper member; brown weathering calcareous shale

Middle member; light-grey siliceous limestone

Lower member; olive-green micaceous shale

Єt

Tintic Quartzite

Buff-to rusty weathering coarse-grained quartzite

strike and dip symbol

fault plane location

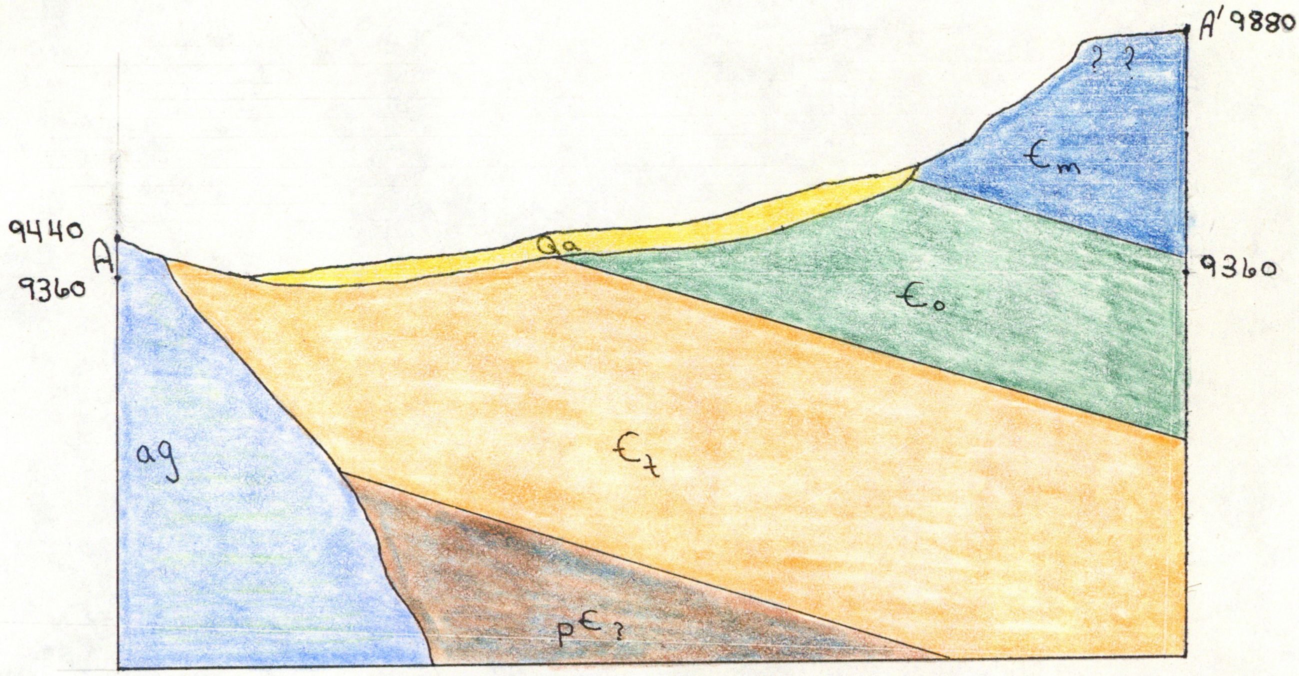

Figure III c

Local Cross Section in Albion Basin

Cambrian	Upper	Maxfield Limestone ϵ_m	Interbedded dolamite and limestones with oolites.
	Middle	Ophir Shale ϵ_o	Green-grey calcareous shale Siliceows Limestone Dark micaceous shale
	Lower	Tintic Quartzite ϵ_t	Light colored quartzite with shale near top

Figure III d

of magnetite, apatite, and occasionally zircon appear. The intrusion shows noticeable lineation and foliation and has several dikes emenating from it.

Stratigraphy of Quarternary Deposits

The Quarternary deposits of the area are much younger than the igneous rocks of the area. They are in the form of glacial deposits, talus, and valley alluvium.

Effects of Contact Metamorphism on the Cambrian Rocks

The effects of metamorphism may be recorded in two ways. The first is the physical appearances of the rock types as they become more highly metamorphosed. The second is the reaction of original minerals with increases in temperature and the subsequent formation of new minerals.

Tintic Quartzite

The Tintic Quartzite is, in the area of lower grade metamorphism, not visible because of faulting and valley alluvium. However, in the visible more highly metamorphosed sections, the quartzite exhibits a noticeable increase in hardness. There is a corresponding increase in the grain size and purity of this rock type. With this increase in grain size there is a decrease in form. The grains initially have better developed crystal form which decreases toward the contact zone. The purity of the formation also increases in the direction of higher grade metamorphism. This is especially noticeable in the upper part of the section.

Apparent remnants of bedding are also present. These beds range from less than an inch to more than several inches thick. The joint pattern is not greatly effected by this increase in metamorphism. It remains near vertical. The color of the weathered surface also tends to go from a red-brown to a darker reddish-brown in the direction of the contact zone.

Samples taken in the Tintic as well as the other formations do not include representatives of unmetamorphosed rocks. Therefore, changes from original minerals to those representative of low grade metamorphism are unrecorded.

The changes in mineralogy coinciding with the increase in temperature are difficult to trace in the Tintic Quartzite. This is most likely caused by its homogeneity. The samples taken in this formation (LCC #9 and LCC #12) do not show any specific mineral assemblages typical of either low or moderate temperature contact metamorphism. They contain mainly quartz with some muscovite. The quartz is not significant while the muscovite may be detrital. They may both be either members of low grade or moderate grade metamorphism. However, they will here be considered as members of moderate grade contact metamorphism, where they would be typical of a quartzo-feldspathic metamorphic assemblage. (Sample description available in appendix)

Ophir Shale

In considering the Ophir Shale there are apparent differences in the physical and mineralogical features of the upper and lower members of the formation. The middle section of argillaceous limestone was not sampled and will not be discussed here. The differences between the upper and lower parts of the Ophir Shale are the result of different calcium carbonate contents.

The lower part lacks carbonate minerals. This lower section of the Ophir shows fissile to thin beds. The bedding doesn't disappear when affected by metamorphism, however, it does become less distinguishable and thicker. Those beds closest to the contact zone are up to several inches thick. Also along with this the original blocky fracture is less evident on approaching the contact in this lower member. The hardness of the rock and the green to brown origianl colors become much darker on approaching the contact.

The upper shale member of the formation is more obviously affected by metamorphism. It quickly loses its bedding and shows banding more prominantly as it becomes more highly metamorphosed. Similar to the lower section there is no great increase in grain size, an increase in hardness, and a darkening of typical colors. However, the original blocky fracture pattern is not greatly affected in the upper member as it is in the lower, and is obvious through the whole section.

In low grade metamorphism, between upper and lower divisions of the Ophir there are distinct differences in mineral assemblages. The lower member, depending on the position at which the sample was taken, has the minerals epidote, actinolite, and micas as typical. While in the upper subdivision of the Ophir Shale calcite and tremolite are typical minerals.

Continuing on in the formation, toward successively higher grades of metamorphism; position, with respect to which subdivision of the Ophir, becomes difficult to determine. This is because of the faulting which occurs near the contact. Therefore, the minerals which are termed typical, of the more highly metamorphosed regions of the Ophir Shale, are from the lower division of that formation. Cordierite is the most recognizable typical mineral of this higher temperature region. This was formed by the mineral reaction of actinolite and epidote with the increase in heat. This heat increase caused the release of magnesium, aluminum, and silica which recrystalize to form the cordierite. The excess residual elements went to form muscovite, biotite, and quartz.

Maxfield Limestone

The most noticeable physical change in the Maxfield Limestone is the disappearance of oolites as higher grades of metamorphism are reached. The color of the formation goes from a grey to a pearly white. Grain size increases, grains become less euhedral, hardness increases, and bedding disappears.

Minerals which typify the area of lowest metamorphism are calcite and dolomite. There is no appearance of talc or tremolite due to low silica content and probable incomplete paragenesis. In regions of higher metamorphic grade, the appearance of diopside and/or forsterite as typical minerals is noted. The heat increase due to a higher grade of metamorphism caused the breakdown of some of the dolomite and calcite to release magnesium and calcium. With the silica present, and that which were introduced by permeating volatiles there was the formation of forsterite and diopside.

Metamorphic Facies

Originally facies were defined by Eskola[5], where he originally defined five metamorphic facies. This classification was based on one hand by conditions of a high temperature and variable pressure (high, medium, and low) The other basis is where the pressure is constant and the temperature is variable. Eskola eventually expanded his classification to eight. This scheme has been further expanded and modified by Turner and Verhoogan[6]. Their facies scheme is based on the environment conditions of contact and regional metamorphism.

The classification of Turner and Verhoogan will be adopted here. This classification is based on increasing temperature and moderate pressures as are encountered in contact metamorphosed regions. They define the Albite-epidote hornfels facies as the lowest temperature contact metamorphic facies. The Hornblende-hornfels facies, Pyroxene-hornfels facies, and the Sanidinite facies are the facies representing an increase in temperature respectively in a contact metamorphosed zone. Of these, the main ones concerned in this study will be the low-temperature Albite-epidote hornfels facies and the moderate temperature Hornblende-hornfels facies.

The Albite-epidote hornfels facies occurs on the outer margine of the contact aureoles. Due to the low temperature of metamorphism, facies development may be incomplete. Recrystallization may commonly be imperfect with the mineral assemblages lacking some of their typical minerals. Also unstable relics and grained metamorphics mask the paragenesis. This is a noteable characteristic of this facies.

The sampling of the area under study doesn't include unmetamorphosed examples. Therefore, the complete extent of the outer zone of this contact aureole cannot be determined.

Metamorphic facies are determined by all the mineral assemblages and their association. This is because some assemblages are common to more than one facies. The mineral assemblages of this area, restricted to the low grade Albite-epidote hornfels facies, are confined to three compositional-type environments. These are, in the excess silica environments, the pelitic and basic hornfels. Here they are represented by the quartz-epidote-actinolite-chlorite-quartz mineral assemblages. These are incompletely developed with the absence of albite and chlorite. The third environment represented here is that of the silica deficient marbles. Here the assemblage is that of the dolomite-calcite-tremolite mineral assemblage. This is also not completely developed with the absence of tremolite.

The Hornblende-hornfels facies appears extensively in contact metamorphic aureoles, especially with intrusions of granodiorite composition. This facies differs from the lower grade Albite-epidote hornfels facies by the development of certain minerals, preferred over those of the lower grade assemblages. In silica rich rocks, under proper physical and chemical conditions, hornblende-plagioclase develop instead of albite-epidote-actinolite. In calcareous rocks, also under proper physical and chemical conditions, diopside-, forsterite, and grossularite bearing assemblages tend to develop. It is also distinguished from the higher grade mineral assemblages of the Pyroxene-hornfels facies by its development of hornblende and micas.

In this area there are samples which exhibit mineral assemblages of the Hornblende-hornfels facies. The compositional-type environments to which these assemblages of minerals are confined are the silica rich pelitic and silica poor calcareous environments. In the silica rich pelitic environment the quartz-muscovite-biotite-cordierite assemblage is recognized. This mineral assemblage is complete in several samples. In the silica poor calcareous environment the calcite-diopside-forsterite mineral assemblage is visible.

There are two more contact metamorphic facies remaining to consider. These are the Pyroxene-hornfels facies and the Sanidinite facies. The Sanidinite facies is restricted to xenoliths in lavas, and dikes near the surface. Hence, this facies won't be considered any further. The Pyroxene-hornfels facies is also typical of shallow (low pressure) depths, and with intrusions of basic magmas (higher temperature intrusions). This is not always the case; they do sometimes occur with granite and granodiorite intrusions. There could be a small Pyroxene-hornfels facies near the contact. However, this does not show by the sampling of this area, and

Faies Map of the Albion Basin

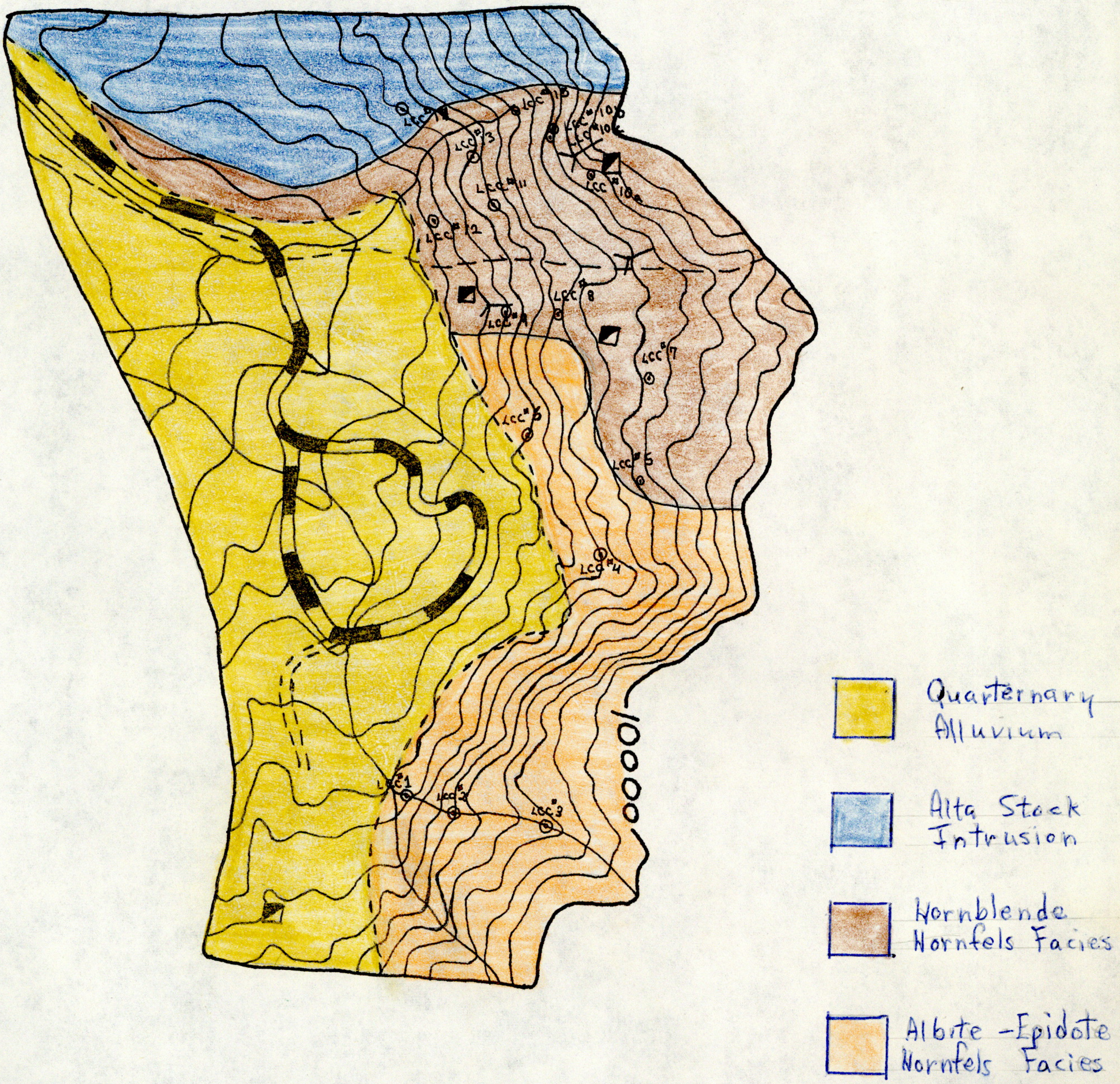

Figure IV

will not be considered further. From the previous discussion a map of the area could be constructed to show the facies distribution of this area. (Figure IV)

Metasomatism

Goldschmidt defined and classified metasomatism and his terminology will be used here. He defines metasomatism as "a process of alteration which involves enrichment of the rock by new substances brought in from outside". This would take place by"definite chemical reactions between the original minerals and the enriching substances". Metasomatic agents may be derived from the intrusion, or from the country rock on reactions induced by the change in temperature of its surroundings.

There are several types of metasomatic alterations, which are possible in a contact metamorphosed aureoles. However, in this area interest is directed to metasomatism with introduction of sulfur and boron. First, the metasomatic introduction of sulfur, as a sulfide volatile, will be considered. The sulfide volatiles react with ferruginous silicates to produce pyrite. Pyrite produced in this manner usually forms rather large pockets of aggregates. In the area of the Alta Stock some of the pyrite may be derived in this manner. However, most is probably not, considering the size and form that the grains exhibit.

The introductory metasomatism of boron is the other form of metasomatism under consideration. In the case of the Cottonwood district there are two different types involved. First, is the formation of tourmaline which is a borosilicate, and was found mainly in the Ophir Shale formation. This is not an uncommon metasomatic product, expecially when associated with a granodiorite intrusion. However, the same applies here as for the pyrite. Some may be formed in this manner, but most, due to its small size and restricted distribution in the samples is likely to be detridal.

The second type of introductory metasomatism of boron forms and uncommon mineral. This is a borate mineral, not a borosilicate, and identified as ludwigite which is fully described in the appendix. It forms in the dolomitic Maxfield Limestone in this area. It is located here in a moderate temperature zone. This is evidenced by its existance with forsterite in the silica poor, calcareous environment of the Hornblende-hornfels facies.

Conclusion

In conclusion the conditions for contact metamorphism must have been at fairly great depths and at moderate temperatures. This is evidenced by the texture of the intrusion and the absence of the higher temperature, lower pressure facies, because these conditions were not met. The intrusion was of large extent as indicated by the known width of the contact aureole. The intrustion also had a noticeable amount of volatiles associated with it, which is typical of granodiorite plutons. But in this case it is of special interest due to the presence of ludwigite.

Appendix

Sample no. LCC #1

Calc- Sericite Hornfels

This is a very fine grain granoblastic Calc-Sericite Hornfels. It contains small vein to bleb-like structures stained with hematite. The xenoblastic matrix is mainly subhedral to anhedral calcite which show no twining or cleavage traces. The matrix has respectively lesser amounts of sericite, hematite, pyrite, and quartz. The isolated structures in the sample contain euhedral calcite likewise not showing any twining.

Sample no. LCC #2

Quartz - Tremolite Hornfels

This is a Quartz-Tremolite Hornfels which is very fine grain, granulose, greenish-grey in color, and somewhat stained by hematite. The matrix is primarily composed of euhedral to subhedral strained quartz grains. There is also oligoclase feldspar, calcite, and small flakes of muscovite. Tremolite appears with a colorless to faint green color and has a xenoblastic texture. Opaque octohedral pyrite and hematite appear in small quantities.

Sample no. LCC #3

Dolomitic Marble

This is a fine grain friable granoblastic pearly white to grey Dolomitic Marble. Calcite in the matrix is in the form of subhedral grains; while in isolated structures it has a coarser euhedral form. Fibrous serpentine is a noticeable constituent of the matrix. Lozenge shape darker grey regions of replacement occur in the sample. Calcite has replaced possibly gypsum or brucite in their fibrous form.

Sample no. LCC #4

Quartz - Epidote Hornfels

This is a green-grey very fine grained Quartz-Epidote Hornfels. Main mineral constituents of the rock are xenoblastic quartz, subhedral epidote aggregates and platy muscovite. Lesser amounts of plagioclase and tremolite appear; with the exact composition of the plagioclase undeterminable due to small size. Opaques of pyrite and hematite also appear in the rock.

Sample no. LCC #5

Diopside - Marble

Sample LCC #5 is a medium grained, blue-grey to pearly white Diopside Marble; composed primarily of calcite (dolomite) with a xenoblastic texture. Some of the grains are also partially reabsorbed. Diopside with euhedral grains is also visable as blades forming a radiating-like structure. Nematoblastic serpentine appears in vein and bleb-like structures. Euhedral tremolite also appears and is usually near the areas of diopside. Opaque pyrite and hematite occur in the sample.

Sample no. LCC #6

Quartz-Epidote Hornfels

This sample is a fractured fine grained white to grey xenoblastic Quartz-Epidote Hornfels. Xenoblastic quartz is primary mineral of the matrix. Lesser amounts of muscovite flakes and green to yellow subhedral grains of epidote. Blue-green tourmoline also occurs as does hematite in smaller quantities.

Sample no. LCC #7

Marble

This is a grey-brown idioblastic medium to coarse grained marble. Calcite with some dolomite exhibit well developed twining with cleavage traces also prominant. Scattered grains of hematite also appear in rock.

Sample no. LCC #8

Cordierite - Mica Hornfels

This fine grained granoblastic brown to bluish grey xenoblastic Cordierite - Mica Hornfels has a typical hornfelsic texture. The matrix contains a great deal of quartz. There is also flakes of muscovite and biotite with larger xenoblastic grains of cordierite. Opaques include hematite and pyrite.

Sample no. LCC #9

Quartzite

This is a medium to coarse grain yellow to grey granulose xenoblastic quartzite. Xenoblastic quartz forms the major part of the rock. Fibrous to platy muscovite and sericite also appear in the section with the sericite altering from the quartz. Hematite and pyrite compose the opaques of the rock.

Sample no. LCC #10a

Forsterite Marble

This is a medium grained pearl white to grey xenoblastic Forsterite Marble. Calcite and dolomite comprise the major minerals of the rock, and exhibit prominant twining. Forsterite occurs in bleb-like structures. Idioblastic ludwigite has a characteristic diamond shaped cross section.

It also exhibits biaxial positive small 2-v optic figure with its birefringent colors masked by the dark brown to dark green pleochroic color scheme of the mineral. Pale green to pale yellow grains of chondrodite with a subhedral form are also present.

Sample no. LCC #10b

Forsterite Marble

This sample is a pearly white granoblastic xenoblastic Forsterite Marble. Xenoblastic prominantly twined grains of calcite and dolomite form the main part of the mineral. Nematoblastic serpentine appear in bleb to vein-like structures with some blebs altered to forsterite. Ludwigite which occurred in sample LCC #10a also appears in this sample and has garnet inclusions.

Sample no. LCC #10c

Quartz - Hedenbergite Hornfels

This is a fine to medium grained green grey Quartz - Hedenbergite Hornfels. The matrix consists of subhedral quartz, perthite, and hedenbergite. Accessories of sphene, biotite, and apatite occur with small grains of hematite.

Sample no. LCC #11

Quartz - Mica Hornfels

This Quartz-Mica Hornfels has a medium grain xenoblastic green-grey form to it. Anhedral quartz is the primary constituent of the matrix. Platy to fibrous grains of muscovite and biotite are commonly distributed in the rock. Sericite and chlorite also appear along with the opaques of hematite and pyrite.

Sample no. LCC #12

Quartzite

This is a medium grained tan xenoblastic granulose quartzite. It is commonly fractured and has quartz as the main mineral, exhibiting a xenoblastic texture. Needle to platy forms of muscovite appear scattered in the rock. Hematite appears as fine grained particles and staining on the rock.

Sample no. LCC #13

Quartz - Mica Hornfels

This is a fine grained white to green-grey nematoblastic Quartz-Mica Hornfels. Nematoblastic muscovite and biotite occur commonly in the sample. Chlorite with some scattered garnets also occur along with ilmenite, magnetite and hematite altering from pyrite.

Sample no. LCC #14

Granodiorite

This is a coarse grain granoblastic blue-green to grey granodiorite. Feldspars of orthoclase, andesine and labradorite are the major constituents of the rock. Quartz and biotite are also prominant minerals along with hornblende. Accessories of zircon, sphene, epidote and m gnetite appear with chlorite and sericite.

Sample no. LCC #15

Kersantite Lamprophyre

This medium grain granoblastic blue green to grey Kersantite Lamprophyre has quartz, biotite, hornblende, orthoclase, and plagioclase in the matrix. Porphyroblastic grains of zoned oligoclase plagioclase, biotite, and quartz are scattered in the matrix. Veins consisting of xenoblastic quartz and oligoclase also appear in the sample. Accessories of zircon, sphene, epidote, and opaques of hematite and pyrite appear. Sericite and chlorite with flaky to fibrous form are also present.

Footnotes

[1]U.S. Geol. Expl. 40th Par. Rept. vol. 1, 1878.

[2]Bontwell, J.M., Geology and ore deposits of the Park City District, Utah; U.S. Geol. Survey prof. paper 77, p. 41, 1912.

[3] Butler, B.S. and Loughlin, G.F.; A reconnaissance of the Cottonwood American Fork mining district, Utah; U.S. Geol. Survey Bull. 620, pp. 165-266, 1915.

[4]Hintze, F.F., A contribution to the geology of the Wasatch Mountains, Utah: New York Acad. Sci. Annuals, Vol. 23, pp. 85-143, 1913.

[5]P. Eskola, Die Entstehung der Gesteine (Barth, Correns, Eskola) p. 344, Springer, Berlin, 1939.

[6]F.J. Turner and J. Verhoogan, Igneous and Metamorphic Petroloby, 2nd ed., McGraw-Hill pp. 508-530.

[7]Goldschmidt, V.M.; On the Metasomatic processis in delicate rocks, Econ. Geol., vol. 17, pp. 105-123, 1922.

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Mineral Samples

for 693.13

by

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Calc- Sericite Hornfels

Sample no. LCC #1

Hand specimen description

LCC #1 is a sample of blue grey very fine grain granoblastic Calc-Sericite Hornfels. It has phacoidal to small vein-like structures stained with hematite and possible lepidoblastic sericite. The main constituent is granular idioblastic calcite.

Thin section study

A granoblastic rock with isolated idioblastic structures embedded in a xenoblastic matrix, with calcite the main mineral. There is also sericite, hematite, and a noticeable small amount of quartz.

Mineralogy

- Calcite -subhedral in matrix, but in isolated structures in matrix it is euhedral; no twining is noticed here.
- Sericite -flakes and fibrous aggregates.
- Quartz -small quantity of subhedral grains.
- Opaques -anhedral grains of hematite, with some euhedral grains where pseudo-morphicly replacing pyrite.

Quartz - Tremolite - Hornfels

Sample no. LCC #2

Hand specimen description

This sample is very fine grain, greenish-grey Quartz-Tremolite Hornfels. The primary mineral seen is quartz with some needles and flakes of muscovite. Hematite is the most prominant opaque mineral which also is staining parts of the sample.

Thin section study

Sample LCC #2 is a granoblastic Quartz-Tremolite-Hornfels with a typical texture of a hornfels. The matrix is primarily euhedral to subhedral quartz with subhedral grains of calcite, oligoclase feldspar, and muscovite. Tremolite has a colorless to faint green color and a xenoblastic texture. Likewise hematite altering from pyrite appears in small pseudomorphic grains.

Mineralogy

Quartz -anhedral to subhedral, strained grains as shown by occasional biaxial small 2-V figure; and it forms the most common mineral.

Oligoclase -xenoblastic grains forming small percent of matrix.

Calcite -xenoblastic grains forming a percent of the matrix.

Muscovite -small lepidoblastic flakes.

Tremolite -subhedral to anhedral faint green to colorless grains often enclosing quartz grains.

Opaques -pseudomorphic hematite after octohedral pyrite.

Dolomitic Marble

Sample no. LCC #3

Hand specimen description

Sample LCC #3 is pearly white to grey somewhat friable granulose Dolomitic Marble. Fine grain idioblastic calcite is the main mineral of the matrix. Small lozenge shaped areas where replacement of a mineral such as gypsum or brucite has taken place.

Thin section study

This sample is a fine grained Dolomitic Marble. Calcite of the matrix is very fine grained and is subhedral to anhedral in form. Isolated structures of coarser euhedral calcite appear in rock. Fibrous colorless serpentine is also a common constituent of the rock. Lozenge shaped areas of replacement which are a darker grey in color occur in the rock. These replace minerals which are possibly gypsum or brucite.

Mineralogy

Calcite and Dolomite - heteroblastic with fine grained subhedral crystals in the matrix and coarser euhedral grains in isolated structures in the rock.

Serpentine(Antigorite) colorless fibrous grains in matrix

Opaques -hematite and pyrite

Replacement Structures-lozenge shaped, grey regions of sample which have calcite replacing previous minerals. This previous mineral was possibly gypsum or brucite.

Quartz - Epidote - Hornfels

Sample no. LCC #4

Hand specimen description

Sample number LCC #4 is a green-grey granoblastic Quartz-Epidote Hornfels with a hornfels texture. The quartz is small and occurs as subhedral grains, with some areas of quartz altering to possibly sericite. Hematite appears as fine grains and stains on the rock.

Thin section study

Sample number LCC #4 is an extremely fine grained granoblastic rock with subhedral to anhedral quartz being most prominant. There is also some yellow-green aggregate epidote and subhedral plagioclase feldspar. Some grains of opaques of an iron oxide, platy to fibrous muscovite, and colorless subhedral grains of tremolite.

Mineralogy

- Quartz -small subhedral to anhedral grains.
- Plagioclase-small subhedral grains, actual composition difficult to obtain.
- Epidote -yellow to green aggregates.
- Muscovite -platy to fibrous grains.
- Tremolite -colorless subhedral to anhedral grains.
- Opaques -red to brown iron oxide.

Diopside Marble

Sample no. LCC #5

Hand specimen description

Sample no. LCC #5 is a blue grey to pearly white Diopside Marble. Euhedral calcite forms the major part of the matrix with some blue grey areas of serpentine. Prismatic diopside forms radiating structures. Opaques of hematite and pyrite appear in rock.

Thin section study

Euhedral calcite appears prominantly in sample with some crystals partially reabsorbed. Serpentine (antigorite) occurs in vein or bleb-like structures. Diopside forms radiating structures; with tremolite and opaques of hematite and pyrite occurring in lesser amounts.

Mineralogy

Calcite and Dolomite - blocky euhedral crystals showing twining and cleavage; some grains have crystal faces partially re-absorbed.

Antigorite -fibrous to platy grains

Diopside -appears as blades which form radiating structures.

Tremolite -colorless subhedral to euhedral prismatic structures.

Opaques -small quantity of euhedral to subhedral grains.

Quartz - Epidote Hornfels

Sample no. LCC #6

Hand specimen description

Sample LCC #6 is a fractured fine grain white to grey xenoblastic Quartz - Epidote Hornfels. The matrix is primarily subhedral quartz, lepidoblastic muscovite, and some grains of epidote. Hematite stains in lenticular regions.

Thin section study

Sample LCC #6 is a fine grain granoblastic Quartz-Epidote Hornfels with a typical hornfels texture. The matrix is formed of subhedral quartz and small flakes of muscovite. Yellow to green aggregates of epidote appear. Lesser amounts of tourmoline and opaques of pyrite and hematite occur in rock.

Mineralogy

Quartz -granulose subhedral grains mainly in matrix.

Muscovite (Sericite) - small anhedral grains in the matrix with some larger subhedral grains.

Epidote -yellow to green grains with subhedral form and is size of larger muscovite grains.

Tourmoline- small bluish-green prismatic grains.

Opaques -octahedral to cubic grains some of which altering from pyrite.

Marble

Sample no. LCC #7

Hand specimen description

Sample no. LCC #7 is a coarse grained grey-brown Marble. The calcite is idioblastic in texture, with hematite as small xenoblastic grains or strains.

Thin section study

This section is idioblastic calcite and dolomite with twining and cleavage prominant. Opaques of pyrite and hematite.

Mineralogy

Calcite -cleavage and twining parallel to the long diagonal occurs.

Dolomite -cleavage and twining parallel to the short diagonal.

Opaques -small amounts of pyrite and hematite.

Cordierite - Mica Hornfels

Sample no. LCC #8

Hand specimen description

Sample LCC #8 is a brown to bluish grey primarily xenoblastic Cordierite - Mica Hornfels. Xenoblastic and partially recrystalized quartz is the major constituent of the matrix, with flakes of muscovite and biotite. Lenticular structures also occur in the rock.

Thin section study

Granulose xenoblastic grains of quartz with lenticular structures with biotite, muscovite, tourmoline, and opaques. The remaining part of section contains megacrysts of cordierite with some small euhedral crystals of sillimanite.

Mineralogy

- Quartz -xenoblastic granulose matrix of section.
- Biotite -small flakes or chip-like grains concentrated in lenses.
- Muscovite -irregular grains larger than biotite.
- Cordierite -irregular oblong grains with many inclusions.
- Epidote -green-brown subhedral to anhedral grains found mainly in lense structures.
- Opaques -hematite, magnetite, pyrite all in subhedral to euhedral form.

Quartzite

Sample no. LCC #9

Hand specimen description

Sample LCC #9 is a medium to coarse yellow grey grained Quartzite. In hand specimen only subhedral grains of quartz appear. With some hematite stains occurring.

Thin section study

This sample is a granulose xenoblastic Quartzite with a typical hornfelsic texture. Principle minerals contained in the sample are xenoblastic quartz. The accessory minerals being muscovite and scattered grains of blue tourmoline. Sericite is altering from quartz with opaques of hematite and pyrite.

Mineralogy

- Quartz -xenoblastic grains.
- Tourmoline -scattered euhedral grains.
- Muscovite -platy to fibrous grains.
- Sericite -altering from quartz
- Opaques -hematite altering from pyrite.

Foresterite - Marble

Sample no. LCC #10a

Hand specimen description

This is a Foresterite-Marble of medium grain pearl white to grey xenoblastic texture. Calcite is xenoblastic in texture, and is the main mineral. Also some light green to yellow regions of foresterite are visible. Some dark green ludwigite grains with an euhedral form occur.

Hand section study

Large xenoblastic grains of calcite and dolomite form major part of the matrix. There are bleb-like grains of foresterite. Ludwigite occurs, and has a diamond cross section and green-brown pleochroic scheme. Chondrodite has a faint green color and occurs near the ludwigite.

Mineralogy

Calcite (Dolomite) - highly recrystalized xenoblastic grains with prominant twins.

Foresterite-bleb-like structures usually near chondrodite and ludwigite.

Chondrodite-small subhedral grains which are pale yellowish-green.

Ludwigite -dark green to dark brown pleochroic mineral. It has a uniaxial to biaxial small 2-v optic figure. Birefringence is masked by color of mineral. It is diamond shaped in cross section, and has a prismatic elongate section. It has an index of refraction greater than calcite.

Foresterite Marble

Sample no. LCC #10b

Hand specimen description

Calcite is the primary mineral in a pearly white Foresterite Marble of medium grainsize. The calcite is xenoblastic and granulose. Small faint green to yellow regions of foresterite occur with some nematoblastic serpentine. Samll grains of magnetite occurs in the rock.

Thin section study

The primary mass is highly twined granulose xenoblastic calcite. Included in the section are vein to bleb-like structures filled with antigorite which is altering to foresterite. Ludwigite with its euhedral form and high refractive index appears in rock. Also there are accessories of magnetite and garnet.

Mineralogy

Calcite (Dolomite) - highly twined with a granulose xenoblastic fabric.

Antigorite (Serpentine) - in bleb to vein-like structures which are nematoblastic in texture.

Foresterite-replacing the (serpentine) antigorite.

Garnet -appears as inclusions in ludwigite and is subhedral to anhedral.

Ludwigite -diamond cross-section, dark green to dark brown pleochroic scheme, euhedral grains with high relief.

Magnetite -has subhedral form.

Quartz - Hedenbergite Hornfels

Sample no. LCC #10c

Hand specimen description

Sample LCC #10c is a medium to coarse grain green-grey Quartz-Hedenbergite Hornfels. The quartz exhibits a xenoblastic fabric while the form of hedenbergite is a idioblastic prismatic texture. Hematite with a red-brown color is also present.

Thin section study

This section is a medium grain Quartz-Hedenbergite Hornfels which consists of anhedral quartz, perthite, and xenoblastic hedenbergite. There is also some biotite with accessories of sphene, apatite, and hematite.

Mineralogy

Quartz -subhedral with some showing biaxial small 2-v indicating straining.

Perthite -showing microcline with albite intergrowths.

Hedenbergite- pale green to green pleochroic scheme in euhedral

Biotite -flakes of a brown pleochroic scheme.

Sphene -blue-grey euhedral grains.

Apatite -typical prismatic form.

Sericite -altering from the perthite.

Opaques -small subhedral hematite.

Quartz - Mica - Hornfels

Sample no. LCC #11

Hand specimen description

Quartz - Mica Hornfels is a xenoblastic green-grey medium grained typical hornfels. Anhedral grains of quartz are most recognizable mineral of matrix. Small anhedral needles of muscovite occur. Grains of hematite along with iron oxide staining show in specimen.

Thin section study

Sample LCC #11 is a medium to coarse grain xenoblastic Quartz - Mica Hornfels. With subhedral to anhedral quartz as main mineral of matrix. Smaller amounts of orthoclase, muscovite, biotite, and opaques are also present. The opaques are hematite altering from pyrite. Sericite is an alteration product of the quartz.

Mineralogy

- Quartz -subhedral to anhedral somewhat strained grains. Strained grains exhibit a biaxial small 2-v optic figure.
- Orthoclase -small subhedral grains.
- Biotite -small subhedral platy grains.
- Muscovite -somewhat larger than the biotite and are subhedral flakes.
- Chlorite -green subhedral flakes.
- Sericite -altering from the quartz.
- Opaques -hematite altering from pyrite.

Quartzite

Sample no. LCC #12

Hand specimen description

Medium to fine grain tan quartzite with xenoblastic granulose quartz. There are fractures where hematite stains appear. There are also some hematite grains prominant.

Thin section study

This is a xenoblastic fine grain quartzite with random restricted areas of orthoclase. Muscovite grains have a platy subhedral form.

Mineralogy

Quartz	-forms the majority of the mineral with grains showing a xenoblastic form. Some of the grains exhibit a biaxial small 2-v optic figure.
Orthoclase	-subhedral grains which are greatly altered.
Muscovite	-forms small plates to blades

Quartz - Mica Hornfels

Sample no. LCC #13

Hand specimen description

Sample LCC #13 is a vitreous white to green-grey Quartz-Micas Hornfels exhibiting a typical hornfelsic texture. Muscovite and biotite needles and flakes appear with xenoblastic quartz and subhedral to euhedral orthoclase. Garnets and hematite also appear in the rock.

Thin section study

This rock is a fine to medium grain nematoblastic Quartz-Micas Hornfels. Quartz, muscovite, and biotite are the major minerals of the section. Lesser amounts of orthoclase, green chlorite, and garnets appear. The opaques of the section are ilmenite and hematite altering from pyrite.

Mineralogy

- Quartz -xenoblastic grains some of which show strain
- Garnets -colorless with high relief
- Muscovite -platy to needle shape
- Biotite -platy form as seen in muscovite
- Chlorite -irregular subhedral grains with green color
- Opaques -hematite altering from pyrite, magnetite, and black ilmenite.

Granodiorite

Sample no. LCC #14

Hand specimen description

This is a coarse grain blue-green to grey granulose Granodiorite. This is a sample of the intrusion near the contact zone. It contains xenoblastic quartz and euhedral plagioclase. Grains of hornblende and biotite appear in the sample, along with grains of hematite.

Thin section study

This Granodiorite is a medium to coarse grain igneous rock typical of the Alta Stock intrusion. Xenoblastic quartz, subhedral labradorite and andesine plagioclase, and subhedral orthoclase occur. Biotite and hornblende occur with accessories of zircon, epidote, and sphene. The appearances of magnetite, chlorite, and sericite also can be seen.

Mineralogy

Quartz -xenoblastic grains and also fills fractures in feldspars.

Labradorite
Andesine Plagioclase - subhedral to euhedral grains which are fractured with quartz filling fractures.

Orthoclase -few subhedral to euhedral grains which are fractured.

Biotite -euhedral flakes

Hornblende -euhedral grains with inclusions

Accessories-zircon, sphene, epidote, and magnetite

Alterations-chlorite and sericite

Kersantite Lamprophyre

Sample no. LCC #15

Hand specimen description

Sample LCC #15 is a granoblastic blue-green to grey Kersantite Lamprophyre. This is a dike emanating from the granodiorite intrustion. The matrix is anhedral quartz and subhedral biotite. Megacrysts of idioblastic plagioclase and hornblende also occur in the matrix. Prominant veins occur with subhedral quartz and plagioclase. Opaques of hematite and megnetite also appear.

Thin section study

This is a fine to medium grain granoblastic rock with quartz and biotite the major minerals. It also contains hornblende, orthoclase, and plagioclase. Porphyroblastic grains of altered and zoned plagioclase, biotite, and quartz are scattered in the matrix. Vein or lenticular structures occur with xenoblastic crystals of quartz and oligoclase. Opaques of pyrite and hematite are also present with some accessories of sphene, zircon, and epidote.

Mineralogy

Quartz -anhedral grains of matrix and in vein or lenticular structures.

Orthoclase -small subhedral grains mainly restricted to the matrix.

Biotite -subhedral megacrysts.

Hornblende -subhedral grains of the matrix

Oligoclase (Plagioclase) - appears in veins and matrix and exhibits twining.

Zircon -red-brown euhedral grains

Sphene -blue-grey euhedral grains

Epidote -subhedral grains

Opaques -hematite and pyrite grains

Alterations-chlorite and sericite appear in subhedral grains